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Immersive Visualization of Complex Situations for Mission Rehearsal

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14. ABSTRACT *(Maximum 200 words)*:

The program objectives of this report included identification of an appropriate rehearsal scenario, as well as the requirements and specifications for necessary computer hardware and software. Key considerations in identifying the training scenario were intrinsic benefit to the Army, effectiveness of virtual environments for training, and benefit from implementation over a distributed computer system.

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Executive Summary

This report documents the work performed under Army contract DASW01-96-C0032 to investigate the application of virtual environment technology to mission rehearsal. The program objectives included identification of an appropriate rehearsal scenario, as well as the requirements and specifications for necessary computer hardware and software. Key considerations in identifying the training scenario were intrinsic benefit to the Army, effectiveness of virtual environments for training, and benefit from implementation over a distributed computer system.

The scenario selected for focus in the program is allied health/emergency medical training. There are literally thousands of candidates for such training each year from both civilian and military sectors. The potential of emergency medical procedure rehearsal over a distributed system such as the Internet has particular benefit in remote military situations such as in on-board ship or overseas operations.

A main consideration in the current program has been to leverage existing capabilities and commercial software/hardware products. To that extent, the program has drawn on the experiences of Professor James Hahn and the George Washington University staff in developing a visual and haptic virtual environment for training surgeons in catheter insertion for interventional radiological procedures. It is proposed that the emergency medical training demonstration include a procedure such as venipuncture or cricothyroicotomy which involves a learned haptic ability. The Phantom, a commercial haptic interaction device manufactured by SensAble Technologies Inc, was selected as the hardware device to be applied in the virtual environment. Software considerations included the language requirement that additional code be written in C++ with Open Inventor, as the primary COTS library. Furthermore, it is proposed that the graphics environment, to the extent possible, follow the specifications contained in the published VRML 2.0 standards. It is also proposed that the virtual environment training system be developed in a "helper application" form which can be used in context with commercial Internet browser software. The user interface will include windows for graphic display as well as a text window for real time text dialog between instructor and trainees. Software and hardware considerations include implementation of the training system on workstation as well as desktop PC platforms.

Implementation of the effort, as identified in this report, as a Phase II SBIR program, is projected to fill a developing need as well as forming a test bed for the investigation of state-of-art concepts in virtual environment based training.

IMMERSIVE VISUALIZATION OF COMPLEX SITUATIONS FOR MISSION REHEARSAL

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Immersive Visualization of Complex Situations for Mission Rehearsal

Fourth and Final Quarterly Progress Report

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1. Introduction

This document constitutes the fourth and final quarterly report describing progress undertaken in performance of ARMY contract DASW01-96-C-0032 -- "Immersive Visualization of Complex Situations for Mission Rehearsal." The objectives of the program are twofold. The first is the identification of requirements inherent in using commercial off-the-shelf (COTS) hardware and software to develop a military and non-military immersive virtual environment (VE) rehearsal and training system. The second is the establishment of functional system specifications and recommendations for specific COTS hardware and software as well as custom designed hardware and software systems.for a specific virtual environment rehearsal and training system.

The previous quarterly report identified medical rehearsal and training as the specific domain proposed for continued investigation. To provide the leveraged benefit of existing research, it was further proposed that the functional specifications and hardware recommendations be based on extensions of ongoing surgery simulation research being done at George Washington University's Laboratory for Advanced Computer Applications in Medicine. The present system under development at the George Washington University is a prototype for simulating catheter insertion for interventional radiology procedures, such as those used in inferior vena caval filter placement. The short-term goal of the project is to provide the surgeon with an environment resembling the one actually used in the surgical procedure. The long term goal is to identify the cues and levels of fidelity necessary for an effective simulation environment for rehearsal and training.

The present quarterly report identifies a specific medical domain for the rehearsal and training and outlines software and hardware specifications for such a system. The contents of the report are as follows:

- Outline the need for computer-based virtual-environment simulators for allied health training and rehearsal

- Outline the technical problems associated with such simulators

- Propose studies to measure the effectiveness of the simulation environment

- Propose the use of networked computers for distance learning

- Propose specific commercial off-the-shelf (COTS) as well as custom hardware and software for the proposed system

- Outline functional specifications for such a system

- Propose "downgrading" path for the simulation system to lower cost platforms, such as personal computers, and COTS interaction devices.

2. Allied Health Education

We have identified allied health training and rehearsal as the domain for our simulators. The rationale for our decision are:

- Cost effectiveness

- Large number of trainees

- Potential for benefit to the military

- Effectiveness of using virtual environments for training

2.1 VE Simulators for Allied Health Education

Allied health professionals constitute approximately 6 million individuals or 60% of the total health care workforce. There are over 3,000 programs graduating more than 83,000 students a year (Pew Health Profession Commission, 1993). Allied health professionals provide a complex array of services and fill a variety of roles. Some of the most recognized allied health professionals include emergency medical services personnel, medical technologists, radiologic technicians, respiratory therapists, occupational therapy, physical therapy, and cardiovascular technologists.

Nearly all allied health professionals as well as nurses and physicians are involved in doing invasive procedures. Teaching students these procedures has always been a problem in that most of the learning has been in doing them on patients. While students are supervised in their attempts to learn the procedures, there is considerable possibility for injury or unnecessary patient discomfort. Procedures that are commonly taught to allied health professionals (depending on their discipline) include venapuncture, injections, suturing, thorocentesis, lumbar puncture, cricothorocotomy, and insertion of chest tubes.

In addition to introductory teaching of procedures, allied health professionals need ongoing practice to maintain the skills needed to competently do the procedures. For instance, cricothyroicotomies are not done on a frequent basis by emergency medical personnel, but on the occasions this procedure needs to be performed, it needs to be done competently. The only way to maintain that skill is to practice, but the opportunities to practice are virtually non-existent for most health practitioners.

Development of VE teaching tools is also useful to the military for the same reasons that is useful in general. The military provides a substantial amount of training to allied health personnel, physicians, and nurses. The Army and Navy together train approximately 600-800 medical laboratory technologists alone. VE could be very useful to beginning students in the military. Significant numbers of health personnel are detailed to isolated regions of the world with little opportunity to do the number or variety of procedures necessary to maintain competence. An example of the need to develop ways of maintaining competency for military personnel is the Navy Independent Duty Corpsmen (IDC) or physician (MD) who may be the only medical officers on surface vessels and submarines. If an emergency situation arises in which a patient on ship may need a chest tube inserted, it is highly desirable for that IDC or MD to have access to practice the procedure on a regular basis to ensure readiness when this low-volume procedure is needed. The availability of VE on every ship would provide the basis for continuing competency of medical personnel.

In general VE will provide the opportunities that have not been present to date for health professionals to initially learn and to continue to practice procedures that are needed for patient care.

2.2 Candidate procedures to be simulated

The procedures to be developed are those in which many health professions students need to have competency but that students have limited access for both initial practice and rehearsal. The initial procedures to be developed include venapuncture and cricothyroicotomy. Additional procedures that can be developed include suturing, thorocentesis, lumbar puncture, insertion of chest tubes, insertion of nasogastric tubes, insertion of urinary catheter, and flexible sigmoidoscopy. Development of procedures would include an array of situations for students to manage including doing the procedure on a simulation of a normal patient and patients with specific abnormalities. For example, venapuncture would be developed so that a student could learn and practice to this procedure on someone with normal veins as well as someone with small, constricted veins such as may be found in a patient with diabetes.

3. Measuring the Effectiveness of the VE System

The GW School of Medicine and Health Sciences is fully prepared to integrate VE into the teaching of the allied health students. There are currently nearly 300 on-campus students and over approximately 500 off-campus students enrolled in 8 different health sciences disciplines. All off-campus students are military students. In addition, there are 150 students admitted to medical school each year with a total of 600 medical students.

The diversity and large numbers of students in the School of Medicine and Health Sciences provide the opportunity to compare VE learning experiences with traditional learning experiences. In order to evaluate the effectiveness of this method several steps will need to take place including: 1) faculty development on the use of VE and integration into the student learning experience; 2) identification of space designated as the learning laboratory; 3) review of the curriculum for effective integration of VE as a teaching/learning method.

There are two major issues for measuring performance: Determining the factors necessary for an effective training environment and choosing an appropriate testing methodology.

3.1 Factors necessary for effective training environment

Using current technology, it is impossible to provide an exact reproduction of an actual environment, with all the visual, auditory, haptic, and olfactory feedback present in the real environment. Therefore, it is necessary to pinpoint which types of cues the practitioner relies on the most to perform a particular procedure. The final simulation might include these cues, as well as some sensory substitution, where one sense is stimulated in place of another, because of computer processing limitations. Practitioners from the School of Medicine will be intimately involved in this process, and will provide expert knowledge for the constriction of a pilot study before the actual subject tests are performed. This will allow us to provide the most accurate simulation environment possible for measuring performance.

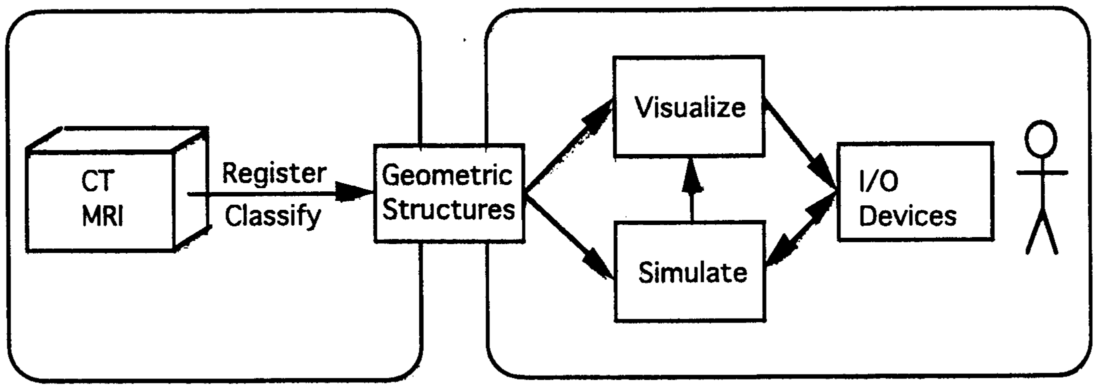
3.2 Proposed testing methodology

The subjects will be pretested, giving a baseline for comparing the influence of the simulator on training performance. One of the main issues to address is how to measure competence in the skill of the procedure. One approach is to query domain experts, such as practicing clinicians. This greatly parallels current evaluation methods, where experienced clinicians are responsible for teaching and evaluating those with less experience. Eventually, we hope to use the computer itself to track performance. Because the computer is providing the simulation environment, it is straightforward to incorporate accounting facilities into the simulation which allow for performance monitoring and evaluation.

4. Simulation System

We have used rigorous system design and development strategies when implementing the current version of our catheter simulation. The code has been structured in a modular, object-oriented fashion, providing functional separation and generality which makes it amenable to reuse. Much of the technology from the present simulator can be transferred. Our philosophy is to use COTS hardware/software wherever possible to reduce cost of the prototype as well as make it easier to transition to production environment.

There are four essential components in a VE simulation system: data generation, simulation of the physical interaction of the tissue with the instruments, visualization of the simulation, and interaction of the user with the simulation.



VE Simulation Environment

4.1 Data generation

There are two general techniques of generating data for medical simulations: segmentation from real anatomical data and by sculpting. We have used both approaches in our simulators. The data for segmentation were gathered from the National Library of Medicine's Visible Man project and from Magnetic Resonance Angiograms (MRAs). We have been using a variation of the Marching Cubes [Lore87] algorithm for segmenting surface structures (like the surface of the bladder) and a wave propagation method [Zahl95] for segmenting blood vessel structures.

4.2 Simulation

To provide a high rate of interactivity, we have employed a combination of physical laws [Hahn88, Lee96] and approximations to simulate movement in the VE. Kinematic approaches have been augmented with pseudo-dynamics to simulate the interaction of the catheter with the surrounding tissue. For some applications, we foresee using pre-calculated trajectories and scenarios (animations) along with limited user interactions.

4.3 Visualization

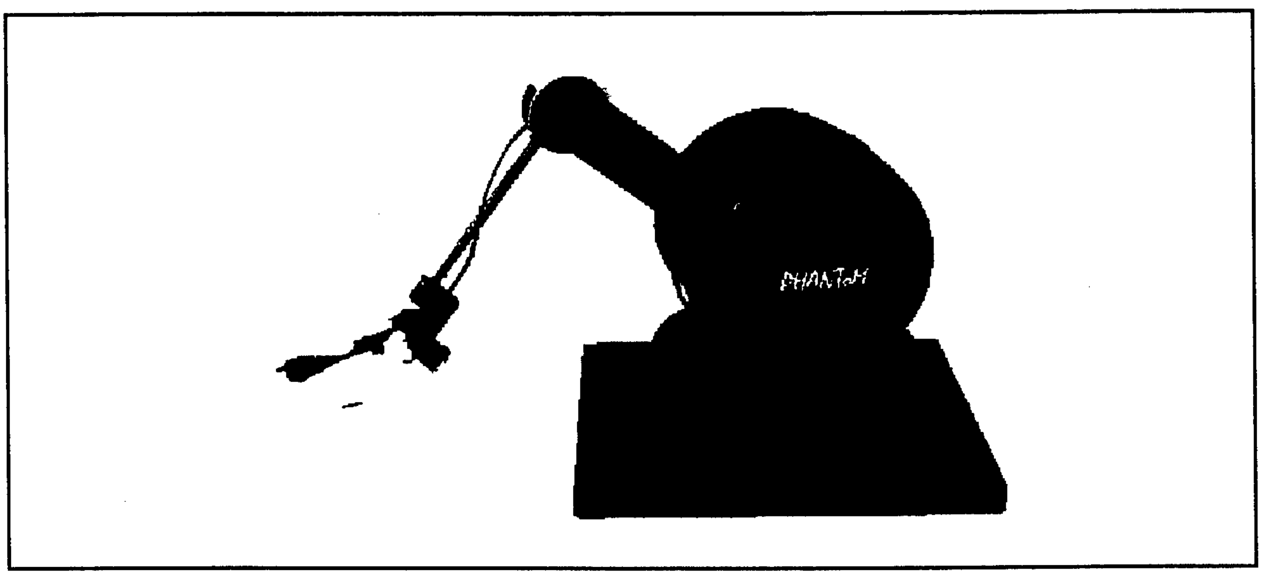
The current system [Park96] is based on mainstream programming interfaces, namely C++ and OpenInventor. The computing hardware necessary for the system consists of the moderately powerful Silicon Graphics Impact workstation, providing us with the texture memory necessary for the pseudo-volumetric rendering used in the simulation for representing the surrounding tissue. By taking advantage of the limited camera movement in the procedure, we have precalculated views from all possible viewpoints, which we can load and display at interactive rates during an interaction session. Thus, we have struck a balance between realism and interactivity.

4.4 Interaction

In our current implementation, we have been using a custom hardware for interfacing with the simulation. The hardware provides 2-Degrees of Freedom (DOF) input as well as 2-DOF haptic feedback. For many procedures, such a specialized device is necessary for a faithful reproduction of the real interaction. In our present simulator, for example, it would be difficult to reproduce the long travel of the catheter (up to a meter) along one of the DOF using a general interaction device. Using such specialized devices has the critical drawback of requiring a different device for each interaction. One-or-a-kind devices, such as these, are also expensive.

For these reasons, we propose using a general COTS haptic interaction device. Such a device would allow a variety of interactions to be simulated using the same device. The tradeoff is that the quality of the interaction would suffer. Some interactions would be difficult to reproduce faithfully. It may be necessary to replace a particular mode of interaction with a substitute.

Currently, there are very few general haptic interaction devices on the market. One of the most successful such devices is the Phantom. Phantom is a general 3 translational DOF haptic interactive device with 3 additional rotational DOF input capability manufactured by SensAble Technologies, Inc., 26 Landsdowne Street, University Park at MIT, Cambridge, MA 02139. This device is currently used by many commercial and educational laboratories who report excellent flexibility, realism, and overall price/performance ratio.



Phantom haptic device

4.5 Simulation platform

Silicon Graphics (SGI) machines have achieved a standard status in real-time graphics visualization. What was at one time performance restricted to "supercomputer" class machines is beginning to be available in relatively inexpensive desk-top machines. In medical simulations, it is not uncommon to see polygon counts in the range of several thousand. These are usually shaded using Gouraud shading techniques. For realistic appearance, it is important to have complexity afforded by texture mapping.

The new class of O2 graphics workstations from SGI is capable of approximately 300,000 Gouraud shaded triangles per second as well as hardware texture mapping We foresee processing capability of R10000, 64MB memory, and 1GB disk to be a reasonable configuration.

5. Distributed VE System

A particularly novel aspect of the proposed rehearsal and training system is its integration with a distributed computer network. The distributed network itself can be a system of local computers tied into a single server (Local Area Network or LAN) or in its broadest application, the global network of computers comprising the Internet itself. The important factors in consideration for a distributed mission rehearsal and distant learning environment are: the type of immersion of the participants and the system configuration.

5.1 Distributed VE System and Distant Learning

The application of distributed computing to educational systems is a modern trend born from the exploding availability of networked systems. The Open University in the UK is an example of this trend. Currently more than 218,000 people are studying with the Open University. Educational programs offered include programs in management, education, health and social welfare, manufacturing and computer applications. A unique feature of the Open University is that specially prepared teaching materials are delivered to the students in their own homes or places of work - by mail, computer, and via national BBC broadcasts. Educational institutions within the United States such as Tulane University, University of North Carolina, and California State University have active Internet "distant learning" programs underway.

The George Washington University has been a leader in distant learning using video links. The Educational Technology Leadership Master's degree was one of the first in the country to use video links and computer technology for the entire program.

Advantages of a distributed learning environment include ease of updating educational materials, ability to connect students and teachers over extensive geographic distances, and the ability to provide a focused curriculum to a large number of students.

5.2 Type of Immersion

The type of immersion for our purposes can be divided into three broad categories:

- passive observation where the participants see the procedure as if they are looking at a movie.

- active observation where the participants can change his/her point of view as well as the representation of the information but not the simulation itself.

- active interaction where the participants feel as if they are operating on the same patient.

"See" can be interchanged with "hear" as well as "feel" in the above classification. Passive and active observation can be implemented in the same way as VRML where the data is loaded from a remote site and the user interacts with a predetermined simulation. This can be done over the internet. Active interaction calls for more bandwidth between the two sites and therefore tighter coupling between the sites.

All three types of immersion can conceivably contribute to the mission rehearsal/training experience. We propose experimenting with prototypes of all three types of immersion for their effectiveness.

5.3 System Considerations

Formulation of the distributed VE requires making several fundamental system choices. One of the early choices is the data transmission protocol to use for communication between computers. Although a number of protocols exist, the two most common flavors are TCP (Transmission Control Protocol) and UDP (User Datagram Protocol). The main difference is that TCP includes guaranteed message addressing while UDP although running significantly faster, does not guarantee message arrival. The TCP protocol includes performing checksums on data packets and requesting retransmission when required. UDP is a so-called stateless protocol, which requires each message to be self-contained, having no relationship to earlier messages. UDP broadcasts are used on the military Distributed Interactive Simulation (DIS) network. TCP is used "on top" of the Internet Protocol (IP) using IP to transfer messages between host computers.

Because of its dominant use on the Internet, the current specification is based on using the TCP protocol.

Along with the choice of network protocol is the consideration of network topology. The two fundamental network models are the centralized or star model and the distributed model. The centralized model uses a single host computer. Each networked computer conceptually connects directly with this host. The host computer receives information from each of the clients, processes the information and retransmits the update. In the distributed model, there is conceptually no central host. Each computer in the system has a complete system database. Each computer transmits information directly to all the other networked computers. The primary benefit of the centralized model is the basic simplicity of the networked arrangement. Its biggest drawback is that the system can slow down significantly as the central host tries to keep up with a number of added computer clients. For application to the current specification, it is proposed to use the centralized topology model. In a LAN implementation, the LAN server itself is the natural communications center. In an Internet implementation, there will be a host server, which controls the communications to the "student" Internet sites. Although proposing the use of a centralized system, the specification will require that each client computer perform as many intrinsic functions as possible. The client computers will, for example, maintain their own visual, audio and haptic software rendering engines. The main function of the centralized computer will be to provide continuing updates of the rehearsal scenario.

Simulation can be distributed over the network or reside locally on each machine in parallel. For performance considerations, we propose a local model where the message passing is strictly for synchronization of the simulation.

5.4 VRML

A major consideration in the proposed specification is to use make maximum use of existing software standards and COTS software and hardware. In that regard, it is proposed that the software development follow the VRML specification to the extent possible. VRML or Virtual Reality Modeling Language constitutes an ASCII based descriptive format that is interpreted by world wide web browser. Version 1.0 of the VRML specification describes the format for presenting static text and 3 dimensional objects. The format has been recently extended (VRML Specification 2.0, August 1996) to include other features such as animation. Under current consideration for a VRML 2.0 update or VRML 3.0 specification, however, is extension to multi-user interaction capability. The current VRML specification also does not include the capability of driving a haptic device.

The medical rehearsal and training interface will take the form of a world wide web browser. As with existing browsers, it should provide interface to the Internet as well as LAN networks. In this fashion, the interface approach follows the current trend of paralleling Internet and Intranet commonality. The VRML browser should be written in the form of an add-in or helper application which works in conjunction with a commercial world wide web browser such as Netscape or Internet Explorer. When a web browser user opens a file with an .wrl file extension, the VRML browser would then be activated.

It is proposed that the software be written in C++ with OpenInventor as the primary COTS library. The OpenInventor file format was the springboard for VRML. OpenInventor provides visual rendering, event handling and interactivity , thus constituting a convenient, integrated, reliable and fast database engine. It does not, however, include the ability to communicate directly with any "virtual reality hardware" other than a monitor display.

The approach to integrating VRML with a haptic device will be to first amend the current VRML 2.0 specification by adding a "haptic" node. VRML can be considered as a file format for describing objects. Objects include 3 dimensional forms, sound files, images, textures, etc. Each object, or node, contains elementary data stored in fields and events. As stated in the VRML 2.0 specification a node has the following characteristics:

- A type name.- A name which identifies the generic kind of node

- The parameters that distinguish a node from other nodes of the same type.-A separate haptic node would be required to handle different haptic training devices

- A set of associated events that nodes can receive and send. - These events relate to the haptic device position coordinates and the sensory forces to be transmitted.

6. Port to Low-Cost Platforms

Once factors leading to an effective mission rehearsal environment has been identified, we intend to explore porting the simulator to a low-cost system (possibly PC using COTS software/hardware). The port would involve degradation of performance. Such degradation would have to involve the optimization of the learning experience based on studies of factors for effective learning environment. It may also involve substitution of one set of cues for another due to cost considerations (such as aural for haptic). Such systems may not necessarily try to replicate the effect of a full-cost simulation system. The analogy can be found in flight simulators where PC based trainers are used to supplement full-motion, high cost simulators. They focus on different aspects of the training experience.

6.1 Rationale

Some high-end graphics workstations from SGI are still expensive, and many institutions cannot afford them. Meanwhile, they may already be equipped with PCs and Windows environment, both of which are widely used. Therefore porting the simulator to low-cost PC platforms make training available to a wider audience.

6.2 System Specification

Currently, there are some relatively inexpensive 3D graphics accelerator cards available which would accelerate the 3D graphics performance of an PC to that comparable with high-end SGI workstation.

AccelPro TX graphics accelerator from AccelGraphics just released their new high-end OpenGL pipelined 3D graphics accelerator for under $3000 [CGW1011]. They claimed this new board has a hardware texture mapping capability with 3MB to 8MB VRAM, and has a power of delivering 500,000, 25-pixel, Gouraud-shaded, Z-buffered triangles per second, which is about a half of the power of $30,000 SGI workstation has. In other words, the price/performance ratio for the PC/card combination is now even better than the SGI workstation which costs about the same as a top-of-the-line PC and 3D graphics card.

From the software point of view, OpenGL is included in the version of Windows NT, and Template Graphics Software (TGS) licenses OpenInventor from SGI and sells a version for PCs for under $800 [TGS]. The latest version also includes VRML 2.0.

7. Functional Specification

The VE rehearsal and training environment for allied health education has to meet certain functional specifications for it to be successful.

7.1 Simulation environment

The software and hardware system for the simulation shall allow the user to pick a procedure from a range of procedures. Using a combination of visual, auditory, and haptic cues, the system allows the user to go through the simulation. The simulation may not necessarily reproduce exactly all the cues in a real procedure but at least those that contribute to the learning and rehearsal experience. In this regard, it may substitute some senses for others (e.g. auditory for tactile or some haptic DOF for others). Certain performance metrics are gathered throughout the procedure (e.g. amount of total time, maximum force applied, etc.). Procedures can be "recorded" and played back (including "ideal" execution of the procedure). Quantitative evaluation of the performance is generated for each trial run. During the simulation, certain additional information (such as suggestions from the system) is given to enhance the learning experience.

7.2 Distributed environment

The software for implementing the medical training shall have a graphical user interface which facilitates communications between instructor and trainees over the distributed computer system. The training scenario should provide a sense of a classroom session where the instructor is providing the main source of information, but individual students can ask timely questions. The instructor as well as each of the students should receive a near simultaneous and complete transcript of all communications. As in real classroom sessions, a trainee can ask for clarification of a particular concept, thus providing an additional stimulus for other trainees. In a Phase II program the communications between instructor and trainees can be limited to typewritten text. Future considerations could extend this to direct audio conversation.

The user interface for a Phase II program would include a text window which includes a notation of who is commenting and the pertinent text statements. The implementation would be similar to existing Internet Relay Chat (IRC) and interactive 3-D world communication mediums.

8. Conclusion

We have outlined the need for VE simulators for allied health rehearsal and training for civilian and military. We have also outlined the system and functional specifications for an effective system based on COTS hardware and software as well as custom software.

There are two essential factors that make such a system viable: our experience in building such a system and the close co-operation between the School of Engineering and Applied Science and the Health Sciences Program at the George Washington University.

9. References

[Hahn88] Hahn, J. "Realistic Animation of Rigid Bodies," *Computer Graphics*, Association for Computing Machinery (ACM SIGGRAPH), Vol. 22, No. 4 (August 1988), pp. 299-308.

[Lee96] Lee, S., Chwa, K., Hahn, J., and Shin, S. "Image Morphing Using Deformation Techniques," Journal of Visualization and Computer Animation, Volume 7, Issue No. 1, January-March, 1996, pp. 3-23.

[Lore87] Lorensen,W. and Cline, H. "Marching Cubes: A High Resolution 3D Surface Construction Algorithm," Computer Graphics, July 1987, Vol. 21, ACM SIGGRAPH, pp. 163-170.

[Park96] Park, Y, Lindeman, R, and Hahn, J. "X-Ray Casting: Fast Volume Visualization Using 2D Texture Mapping Techniques," Proceedings of IEEE Visualization 96, San Francisco, CA, October 1996.

[Wern94] Wernecke, Josie, "The Inventor Mentor", Addison Wesley, 1994.

[Zahl95] Zahlten, C., Jurgens, H., and Peitgen, H. "Reconstruction of Branching Blood Vessels From CT-Data," Visualization in Scientific Computing, Springer-Verlag, pp. 41-52, 1995.